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LABORATORY STUDIES OF FISH DIVERSION BY LOUVRE GUIDANCE SYSTEMS

Report No 84-149-K

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ABSTRACT

Laboratory studies in a 15 m x 1.2 m x 1.2 m flume determined the effects of louvre parameters (frame ratio, slat spacing, slat angle, water velocity) on diversion of active and passive (anaesthetized) rainbow trout (15 cm juveniles). Passive diversion averaged 10% lower than active diversion. Increased water velocity (20 cm/s to 40 cm/s) significantly decreased passive diversion, but had little effect on active diversion. All other parameters significantly affected both active and passive diversion. Optimum diversion (100% active, 96% passive over all velocities) was obtained using a 4:1 frame ratio, 10 cm slat spacing and 45° slat angle. Use of lower frame ratios, wider slat spacing, acute slat angles and high velocity at the downstream end of a louvre array may allow separation of active and moribund fish. Limited ancilliary tests indicate that trout diversion success was not adversely affected by darkness, smelt diversion (15 cm adults) was comparable to trout results, and gizzard shad diversion (30 cm adults) was superior to trout results.

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To Dr. W.R. Effer
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LABORATORY STUDIES OF FISH DIVERSION BY LOUVRE GUIDANCE SYSTEMS

J.S. Griffiths

1.0 INTRODUCTION

This report describes laboratory studies of fish response to experimental louvre guidance systems. The study was requested by the Environmental Studies and Assessments Department with funding being provided from the Ontario Hydro Capitalized Once-Through Cooling (COTC) Program.

In order to alleviate fish impingement problems in the condenser cooling water (CCW) systems of Ontario Hydro thermal generating stations, one approach which has been investigated as part of the COTC program is the removal of entrapped fish from intake forebays, with subsequent return to the lake. Several COTC studies have examined the feasibility of fish removal using open-impeller (Hidrostal) pumps and pipe loops, as well as methods to improve the capture efficiency of these pumps (Ontario Hydro Research Division Reports 82-295-K; 83-142-K; report in preparation, D.W. Rodgers). However, for any removal system to operate efficiently, fish must first be removed from the general intake flow and concentrated into a relatively small area. Studies conducted by the Research Division have investigated the use of sequenced mercury vapour lights (Ontario Hydro Research Division Report 83-250-K; funded by Research Division) and bubble screen diversion systems (Ontario Hydro Research Division Report in preparation, W.E. Carey; funded by COTC) to concentrate fish in specific regions of intake forebays. The present study investigates the use of a third alternative, a louvre system, for guiding fish to specific regions of intake forebays.

Several studies have indicated that louvre systems can effectively divert fish in test flumes similar to generating station intake forebays (Stone and Webster 1975, 1977; MacLaren, 1975). However, as a rather wide variation in fish diversion success has been obtained from different louvre designs, the objective of the present study is to determine the effects of various louvre design parameters on fish diversion success. The parameters considered were the general angle of the louvre array to the flow (frame angle) the angle of individual louvre slats, the spacing between slats, and water velocity. Of particular interest was the slat angle. Most louvre investigations (see review by MacLaren, 1975) have utilized louvre slats which were perpendicular to the support frame. Thus, the slats were oriented obliquely to the flow and tended to divert flow through the louvre array. In the present study, slat angles were considered in relation to the flow direction and ranged from 90° to oblique angles (as low as 30°) which tended to divert flow towards the louvre by-pass channel. It was assumed that such slat angles would be more conducive to fish diversion.

The louvre design parameters were tested in factorial experimental designs, resulting in 81 treatment combinations which were tested in triplicate. Thus, a lengthy test period (several months) was required. Difficulties in long-term maintenance of large numbers of pelagic schooling Great Lakes species such as alewife and smelt (which make up the bulk of impingement losses at Ontario Hydro generating stations) precluded the use of these species in the present study. Juvenile rainbow trout *(Salmo gairdneri)* approximately 15 cm in length were used as a test species. These fish were comparable in size to adult alewife or smelt and were active, strongly swimming fish which produced consistent results over an extended time period. For comparative purposes, a few tests were conducted with rainbow smelt *(Osmerus mordax)* and gizzard shad *(Dorosoma cepedianum)* at the end of the experimental period.

2.0 APPARATUS AND PROCEDURES

2.1 Louvre Test Facility

A large recirculating flume located in the Flow Systems Laboratory was used for these experiments. The flume was approximately 15 m in length and 1.2 m in depth and width. A large pump (75 hp) discharged into one end of the flume. Water was withdrawn from the bottom of the flume at the opposite end and returned to the pump via a conduit located beneath the flume. When the pump was operated at maximum capacity, current flow approximated 20 cm/s when the flume was filled to a depth of 80 cm. Higher velocities were obtained by reducing water depth in the flume.

The flume was supplied with a continuous flow of dechlorinated Toronto tap water, and depth was regulated by a standpipe overflow. This water inflow, plus the addition of two 1 hp portable water chillers located at the head of the flume (near the pump discharge) maintained flume temperatures within a few degrees of line ambient water temperatures.

The test flume was constructed of clear plexiglass sheets, supported by an aluminum frame. The entire flume plus a walkway along one side was surrounded with opaque curtains to eliminate disturbances from the surrounding laboratory . Incandescent lighting above the flume was adjusted to provide a low level "daylight" illumination of approximately 10 lux.

The louvre test system (Figure 1) was constructed at the rear or downstream end of the flume. The flume was divided into "louvre" and "bypass" areas. The louvre area was 92 cm in width and the bypass was 28 cm in width. Three louvre support frames were constructed, using ratios of 1:1 (45° angle to flow), 2:1 (26.6° angle to flow) and 4:1 (14.0° angle to flow). The louvre support frames (constructed of 5 x 10 cm cedar) were drilled to allow attachment of louvre slats at 10, 20 or 30 cm intervals. The louvre slats (80 cm high x 30 cm wide) were constructed of 14 mm thick plywood. Each slat was attached to the support frames (top and bottom) by a centrally located steel pin which allowed the slats to be rotated into the flow at desired test angles. Slat angles of 90°, 67.5°, 45° and 30° (relative to the direction of flow) were tested with the most oblique (4:1) louvre array (Figure 1). With the 2:1 louvre array, it was not possible to test the 30° slat angle (at 10 cm spacing, the 30° slats closed to form a solid wall). Similarly, it was not possible to test the 30° and 45° slat angles with the 1:1 louvre frame.

A vertical plywood wall (parallel to the flow) was installed at the downstream end of the louvre array to form the bypass channel. A net divider from the rear of this wall to the end of the tank prevented test fish from mixing once they had been diverted to the bypass (or had passed through the louvres). The entire louvre structure was painted a uniform light grey with a non-toxic vinyl paint.

A coarse screen (1 cm galvanized wire) at the head of the flume prevented test fish from entering the area of the discharge pipe and portable chillers. A second removable screen was added approximately 1 m downstream to form a fish holding area. A single strobe light was mounted above this area (directed

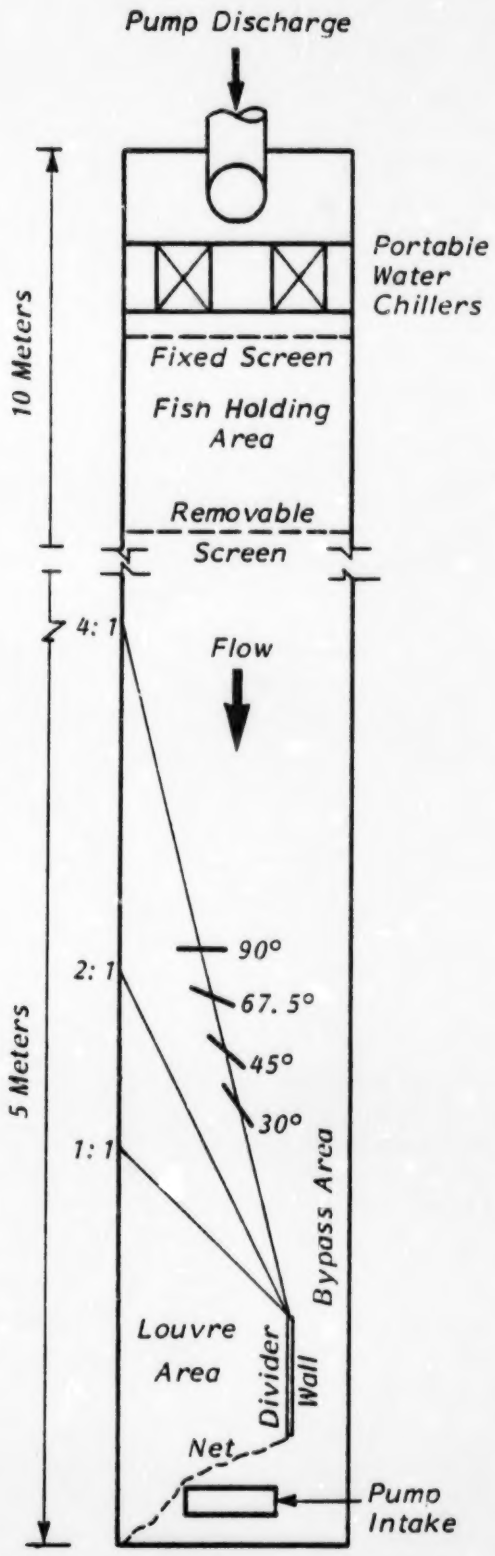

FIGURE 1

SCHEMATIC DRAWING OF LOUVRE TEST FACILITY

towards the bottom of the flume). The strobe light was used to encourage test fish to move downstream (towards the louvre array) once the rear screen was removed.

2.2 Test Fish

Juvenile rainbow trout, *Salmo gairdneri*, were used as test fish. These trout were obtained as fry from the Shamrock Springs Trout Hatchery (Erin, Ontario) in the spring of 1980 and were maintained at the Dobson Research Laboratory until their use in this study during the late summer and fall of 1981. At that time, the fish averaged 15 cm in length. In the laboratory, the trout were maintained under simulated natural photoperiod (daylength adjusted with the seasons) and ambient temperatures (dechlorinated Toronto tap water ranging from 6°C to 20°C). The fish were fed commercial trout feeds and remained in good health throughout the study. Due to the large number of fish required for this study (over 2000) it was necessary to test some trout twice. However, those fish which were re-used had remained in holding tanks for at least one month prior to their second use.

2.3 Experimental Procedures

Prior to the start of each test, 25 trout were placed in the holding area at the head of the flume. The recirculation pump was then started and the fish were left for 30 minutes to become accustomed to the current. The test was initiated by removal of the screen at the rear of the holding area, allowing the fish to move downstream towards the louvre array. The strobe light was turned on at this time to encourage the trout to move downstream. The test was terminated after one hour (or when all fish had passed through the system). In most tests the majority (but not all) of the trout passed through the diversion system within the one hour time period. At the end of a test, counts were made of the fish which had passed through the louvre array or had been diverted to the bypass channel. Results (percentage diversion) were computed on the basis of those fish which had been diverted to the bypass or passed through the louvres. Fish which remained upstream of the louvre system were omitted from computations.

After all fish were removed from the apparatus, they were anaesthetized with tricane methane sulfonate (MS222) then re-introduced at the head of the flume to test the passive diversion capabilities of each particular louvre array. In this test, all fish passed through the test system within a minute or less. Initially each fish was measured (fork length) at the end of active and passive (anaesthetized) tests. However, diversion results did not appear to be correlated with fish length in tests of either active or passive trout and variation in length

was small (typically a range of less than 5 cm in a sample of 25 fish). Therefore, collection of length data was discontinued approximately halfway through the test series.

A total of 81 treatment combinations were tested in this study. Three replicates were run for each treatment. Each replicate included tests of active and anaesthetized trout. Treatments were arranged in factorial combinations of louvre frame ratio (1:1, 2:1, 4:1), slat spacing (10, 20, 30 cm), water velocity (20, 30, 40 cm/s) and louvre slat angle (90°, 67.5°, 45°, 30° with 1:1 frame; 90°, 67.5°, 45° with 2:1 frame; 90° and 67.5° with 1:1 frame).

All the above tests were conducted under low level daylight (approximately 10 lux). Two treatment combinations (90° and 45° slat angles with 2:1 frame, 20 cm slat spacing and 30 cm/s velocity) were also tested using rainbow trout in darkness (three replicates of each treatment). Additional tests of gizzard shad (two replicates) and rainbow smelt (one replicate) were run in low level daylight, using a 4:1 frame ratio (2:1 for smelt), 30 cm slat spacing, 67.5° slat angle and 30 cm/s velocity (40 cm/s for smelt).

3.0 RESULTS

3.1 Active Rainbow Trout

Percentage diversion data for active rainbow trout (tested in daylight) are listed in Appendix 1. In Figure 2, mean results are plotted against louvre slat angle for each combination of slat spacing and water velocity. It is apparent that there was a general trend towards increased diversion success as slat angles became more oblique. Slat spacing also strongly affected results, as diversion success was generally increased by decreased spacing. This was most evident for tests with 10 cm slat spacing (Figures 2G to 2I), where diversion percentages above 90% were observed in most treatments, and several cases of total diversion (100%) occurred. Generally, diversion values below 90% (with 10 cm slat spacing) were associated with the most acute (90°) slat angle. Louvre support frame ratios also appeared to affect diversion success, although differences were not consistent across all treatment combinations. With 30 cm and 20 cm slat spacings (Figures 2A to 2F), the lower frame ratios (1:1, 2:1) generally yielded better diversion at acute slat angles (90°, 67.5°) than the 4:1 frame. The 4:1 frame provided comparable (or better) diversion only when oblique slat angles (30°, 45°) were used. With slats spaced at 10 cm (Figures 2G to 2I), the oblique (4:1) frame was clearly superior, yielding

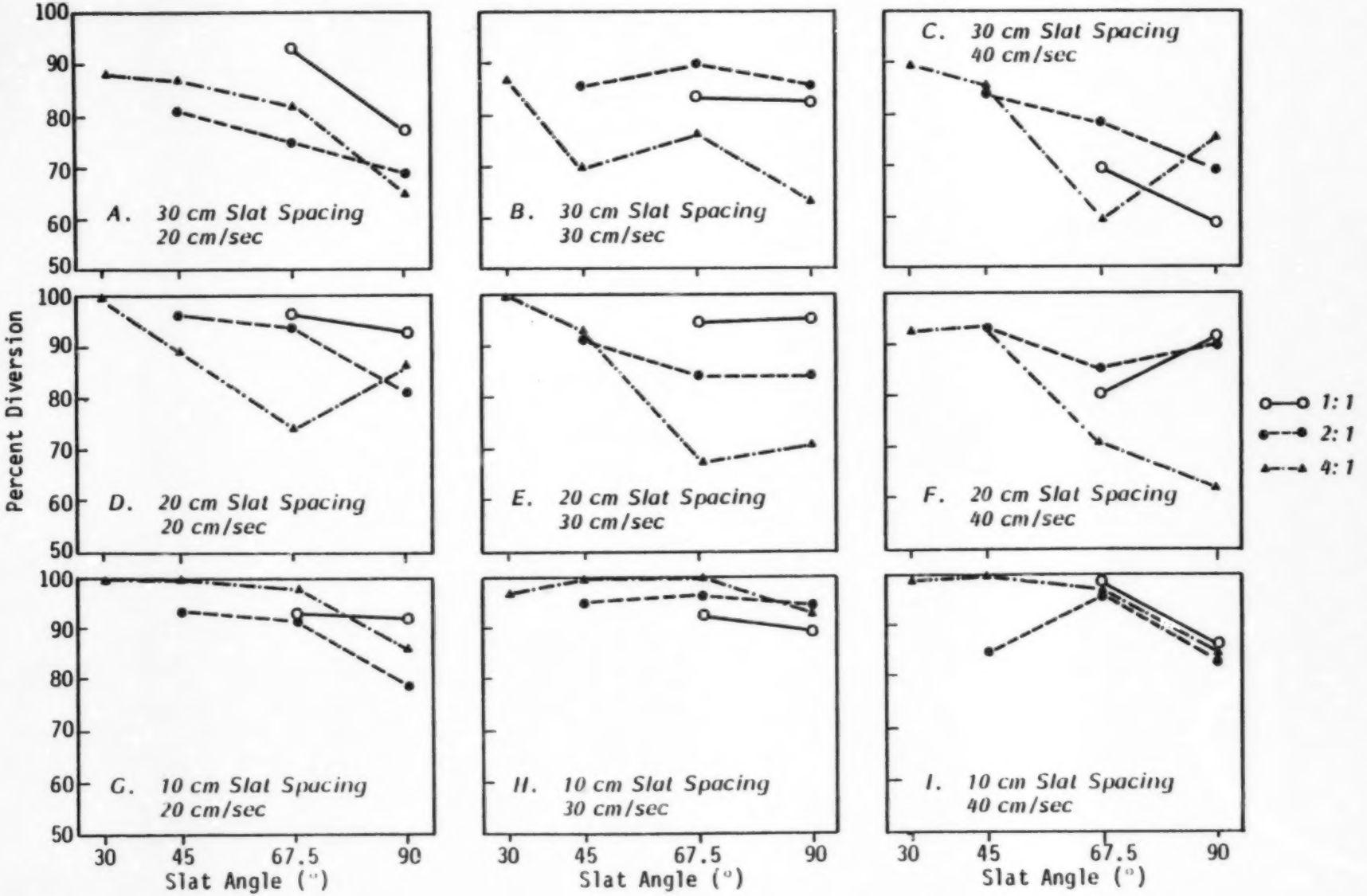

FIGURE 2

ACTIVE DIVERSION OF RAINBOW TROUT IN RELATION TO SLAT ANGLE, SLAT SPACING, VELOCITY AND FRAME RATIO

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nearly 100% diversion for all treatments except the 90° slat angle. Water velocity did not appear to substantially affect diversion success of active rainbow trout. Although poor diversion success (58 to 69%) was obtained with the 1:1 frame and 30 cm slat spacings at the highest velocity (Figure 2C) other treatment combinations did not show a clear decline in diversion success as water velocities increased.

3.2 Anaesthetized Rainbow Trout

Anaesthetized rainbow trout were used to test the passive diversion capabilities of each louvre array and should be indicative of the ability of the louvre system to remove unhealthy or moribund specimens from the intake flow. Percentage diversion results for the anaesthetized trout are listed in Appendix 2. In Figure 3, mean results are plotted against slat angle for each combination of frame ratio, slat spacing and water velocity. As with the diversion of active trout, passive diversion increased with decreasing louvre slat angles. However, trends appear to be less consistent than those obtained with active trout. Decreased slat spacing (to 10 cm) increased passive diversion success for the 4:1 frame ratio, but results were not consistent for the lower frame ratios. It should be noted that combinations of minimal (10 cm) slat spacing and oblique (30°, 45°) slat angles produced very high passive diversion (89% to 100%) at all velocities with the 4:1 frame ratio (Figures 3G to 3I). These results are only slightly lower than the values (96% to 100%) obtained from active trout under similar test conditions. The most oblique louvre frame (4:1 ratio) generally produced the best passive diversion in tests with 30 cm and 10 cm slat spacings. Results for the 20 cm slat spacings (Figures 3D to 3F) were more similar to results from active trout, in that diversion percentages for the 4:1 frame matched those of the lower frame ratios only when the most oblique slat angle (30°) was used. The results in Figure 3 suggest that increased water velocity caused a reasonably consistent decrease in passive diversion. This was most evident for the tests with the largest (30 cm) slat spacing.

3.3 Effects of Louvre Design Parameters on Active and Passive Fish Diversion

Results in Figures 2 and 3 indicated that all louvre parameters investigated have some effect on diversion success of both active and anaesthetized trout, but general trends are to some extent obscured by the large number of treatments (81), limited replication (three replicates) and the inherent variabilty of the data. In order to gain a better representation of effects of the design parameters, mean results for each parameter (summed across all other combinations) are next considered for

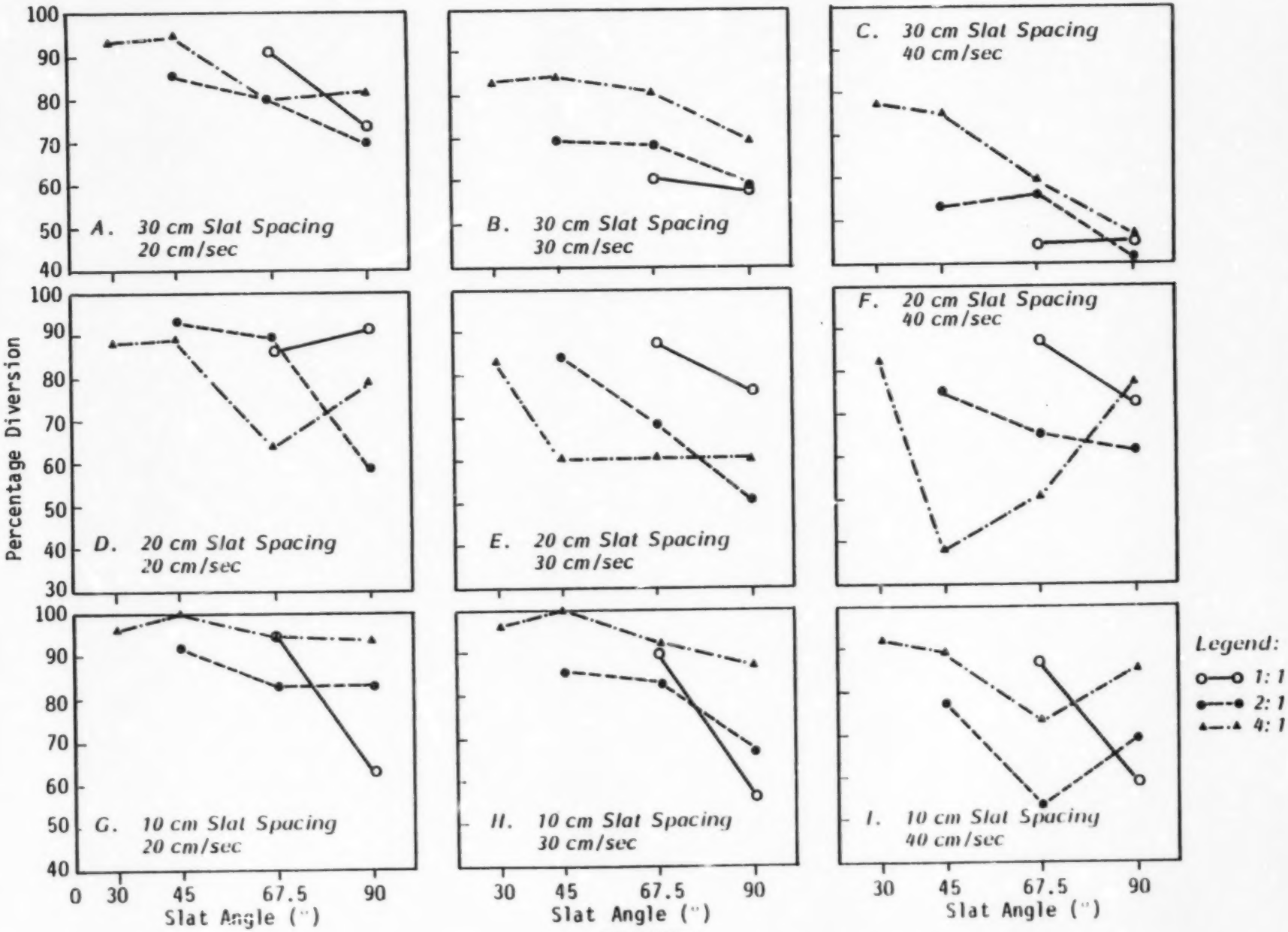

FIGURE 3

PASSIVE DIVERSION OF RAINBOW TROUT IN RELATION TO SLAT ANGLE, SLAT SPACING, VELOCITY AND FRAME RATIO

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both active and passive diversion. Results indicate that slat angle (Figure 4A) strongly influenced both active and passive diversion. For active trout, mean diversion values increased in a linear fashion from 81% with a 90° slat angle to 95% with a 30° slat angle. Passive diversion similarly increased from 68% (90° angle) to 88% (30° angle). Slight divergence of the trend lines in Figure 4A suggests that slat angle may have had a slightly stronger influence on passive diversion. It should be noted that mean diversion values in Figure 4A are not based on equivalent sample sizes, as the 30° slat angle was tested only with the 4:1 frame ratio and the 45° slat angle was tested with only 4:1 and 2:1 frames. While this does not affect comparisons of active and passive diversion, the imbalance of the experimental design required separate statistical analyses (Analysis of Variance) for each frame ratio.

Decreased slat spacing (Figure 4B) resulted in a substantial (largely linear) increase in both active and passive diversion. The increased diversion efficiency appeared to be similar for both active and anaesthetized trout, ie, a 14% to 15% increase in diversion success with a decrease in slat spacing from 30 to 10 cm.

The louvre frame ratio did not substantially affect mean diversion success for active rainbow trout (Figure 4C). However, it should be noted that the use of mean values in this case obscures a real effect. In Figure 2, it was clearly evident that at acute (90°, 67.5°) slat angles, the 4:1 ratio frame was inferior to the 2:1 and 1:1 frames when 20 cm and 30 cm slat spacing was used. Good performance from the 4:1 frame with oblique slat angles (and all slat angles with 10 cm spacing) resulted in mean diversion values for all frame ratios being similar. Mean results for anaesthetized trout indicate best overall passive diversion with the 4:1 frame ratio. As indicated in Figure 3, this oblique frame provided the best passive diversion (at all slat angles) with both the 30 cm and 10 cm slat spacing.

Approach velocity (Figure 4D) had a minimal effect on diversion of active trout, as mean diversion values declined only slightly at the highest velocity (40 cm/s). In contrast, passive diversion was substantially affected by approach velocity, declining from 84% at 20 cm/s to 66% at 40 cm/s.

A series of three-way Analyses of Variance (ANOVAs) were run to determine statistical significance of effects from slat spacing, slat angle and current velocity on diversion success. Due to design imbalance, it was necessary to conduct separate ANOVAs for each frame ratio. The ANOVA tables are listed in

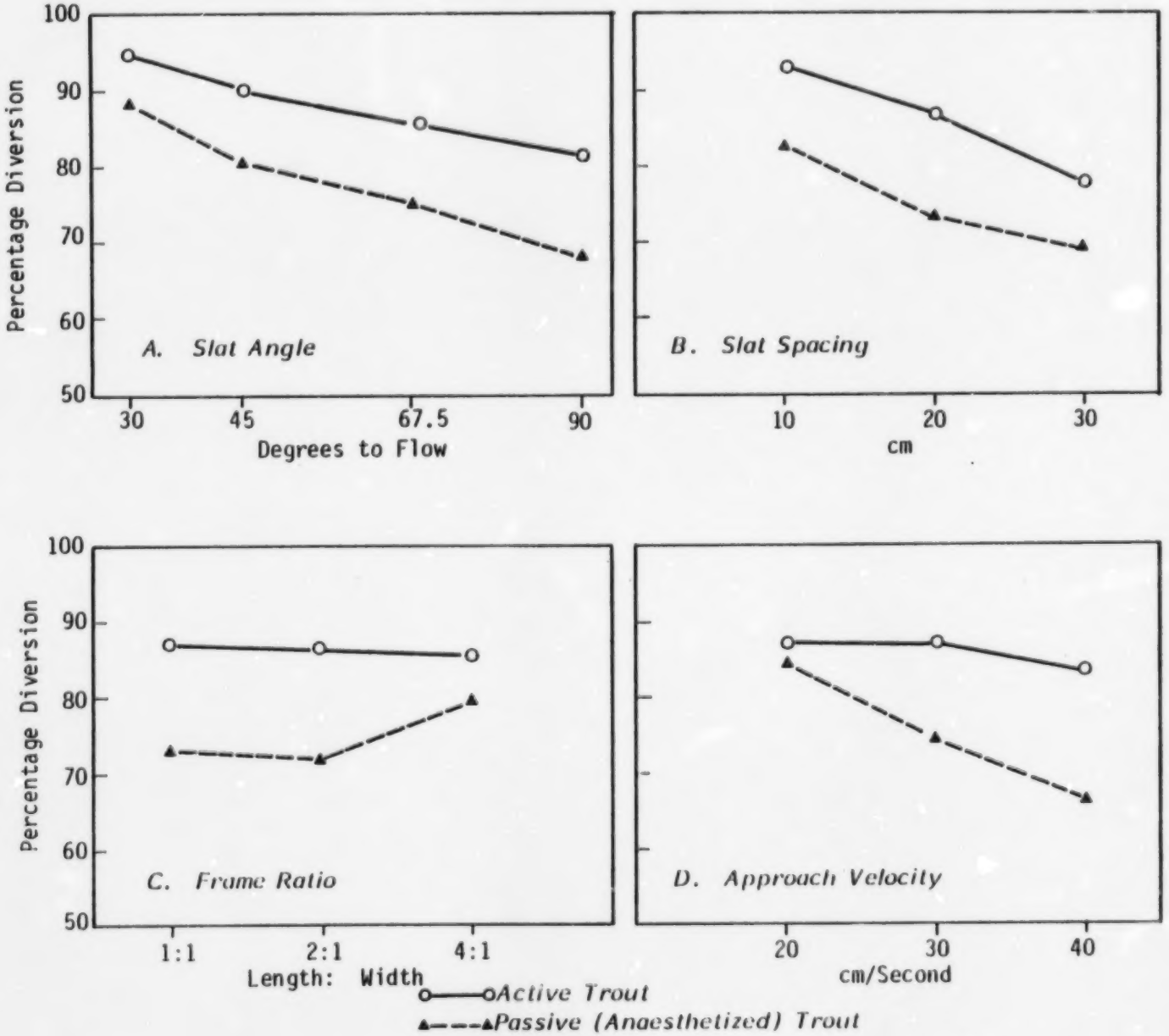

FIGURE 4
MEAN EFFECTS OF LOUVRE PARAMETERS ON DIVERSION SUCCESS

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Appendices 5 and 6 for active and anaesthetized fish, respectively. Multiple range tests (SNK) were conducted for those factors which significantly affected percentage diversion. Results for active trout are listed in Table 1.

In tests of the 1:1 frame ratio, both slat spacing and water currents significantly affected diversion, but slat angle did not. There were no significant interactions between factors (Appendix 5). Results for 10 and 20 cm slat spacing indicate that these two spacings were not significantly different, but both were significantly better than the 30 cm spacing (Table 1A). The multiple range test for current indicates that 20 and 30 cm/s velocities produced similar results (approximately 90% diversion) and both were significantly better than results at 40 cm/s (approximately 80% diversion).

In tests with the 2:1 frame ratio, diversion of active trout was significantly affected by slat spacing and slat angle, but current velocity did not have a significant effect (Appendix 5). There were no significant interactions between factors. The multiple range test for slat spacing indicates that results for 10 cm and 20 cm spacings did not differ significantly and both were significantly better than results with 30 cm spacing (Table 1B). Results with 45° and 67.5° slat angles did not differ significantly, but both angles resulted in significantly better diversion than the 90° slat angle.

The ANOVA for the 4:1 frame ratio data indicated that slat spacing and slat angle significantly affected diversion of active trout, but current velocity did not (Appendix 5). Again, there were no significant interactions between factors. In tests of slat spacing, there were significant decreases in percentage diversion with each increase in spacing (Table 1C). Results for slat angles of 30° and 45° did not differ, but both were significantly better than results with 67.5 and 90° angles.

Analysis of Variance for anaesthetized rainbow trout (Appendix 6) indicated that in tests of the 1:1 frame ratio, slat spacing, water velocity and slat angle all contributed significantly to passive diversion. In addition, significant interactions were observed between slat spacing and current, as well as slat spacing and slat angle. However, the magnitude of these interactions was considerably less than that of the main effects from the spacing, current and slat angle.

As indicated by the multiple range test (Table 2A) best passive diversion (83%) was obtained with 20 cm slat spacing, followed by 10 cm spacing (75%) and 30 cm spacing (62%). These mean values were all significantly different from each other.

TABLE 1

ACTIVE RAINBOW TROUT - MULTIPLE RANGE TESTS (SNK) FOR LOUVRE PARAMETERS

A. 1:1 Frame Ratio			B. 2:1 Frame Ratio			C. 4:1 Frame Ratio			
Multiple Range Test for Factor Spacing			Multiple Range Test for Factor Spacing			Multiple Range Test for Factor Spacing			
30	10	20	30	20	10	30	20	10	
77.2278	91.6778	91.7722	79.4667	88.8407	90.2296	77.2472	83.1778	96.0750	
	**********	**********		**********			**********	**********	
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Multiple Range Test for Factor Current			Multiple Range Test for Factor Angle			Multiple Range Test for Factor Angle			
40	30	20	90	67.5	45	90	67.5	45	30
80.4444	89.4722	90.7611	81.5222	87.6444	89.3704	76.2185	80.3630	90.8037	94.6148
	**********	**********		**********				**********	**********
**********	**********		**********	**********		**********		*********	

TABLE 2

ANAESTHETIZED RAINBOW TROUT - PASSIVE DIVERSION MULTIPLE RANGE TEST (SNK) FOR LOUVRE PARAMETERS

A. 1:1 Frame Ratio			B. 2:1 Frame Ratio			C. 4:1 Frame Ratio			
Multiple Range Test for Factor Spacing			Multiple Range Test for Factor Spacing			Multiple Range Test for Factor Spacing			
30	10	20	30	20	10	20	30	10	
61.7778	74.6667	83.1111	64.5926	71.7037	76.8889	69.6667	76.8889	91.5556	
	**********	**********		**********	**********		**********	**********	
**********			**********			**********			
Multiple Range Test for Factor Current			Multiple Range Test for Factor Current			Multiple Range Test for Factor Current			
40	30	20	40	30	20	40	30	20	
65.5556	70.8889	83.1111	61.3333	70.3704	81.4815	70.8889	79.4444	87.7778	
		**********			**********			**********	
**********			**********	**********		**********	**********		
Multiple Range Test for Factor Angle			Multiple Range Test for Factor Angle			Multiple Range Test for Factor Angle			
90	67.5		90	67.5	45	67.5	90	45	30
65.7778	80.5926		62.0741	71.7037	79.4074	72.5926	75.4074	81.1852	88.2963
	**********			**********	**********			**********	**********
**********			**********			**********	**********		

Results for the lowest current velocity (20 cm/s) were significantly better than those obtained at 30 cm/s and 40 cm/s. The 67.5° slat angle was significantly better than the 90° slat angle (Table 2A).

Tests of the 2:1 frame ratio indicated that slat spacing, current velocity and slat angle all significantly affected passive diversion. There were no significant interactions between these factors (Appendix 6). The multiple range test (Table 2B) indicates that results for 10 cm and 20 cm slat spacing did not differ significantly, but both were significantly better than results with 30 cm slat spacing. Passive diversion decreased significantly with each incremental increase in current velocity and with each incremental increase in slat angle (Table 2B).

The ANOVA for tests with the 4:1 frame ratio indicates that slat spacing, current velocity and slat angle all significantly affected passive diversion (Appendix 6). Small but significant interactions were observed between spacing and slat angles plus current and slat angles. The multiple range test indicates significant differences in percentage diversion with each slat spacing used (Table 2C). Slats spaced at 10 cm produced the highest passive diversion (92%) while 20 cm spaced slats produced the lowest (70%). Each incremental increase in current velocity resulted in a significant decline in percentage diversion. Again, the 30° slat angle produced the best diversion, with results for the 45° slat angle being significantly lower. There was no significant difference between results for 67.5° and 90° slat angles. Both were significantly less effective than 30° and 45° angles.

From the results presented in Figures 2 to 4 and the statistical analyses of these data (ANOVAs) it is apparent that both slat angle and slat spacing significantly affected diversion of active rainbow trout, but current velocity had little effect (over the 20 cm/s to 40 cm/s range tested). Passive diversion (of anaesthetized trout) was significantly affected by slat spacing, angle and water velocity and some significant interactions occurred between these factors. Frame ratio also appeared to affect both active and passive diversion. For active fish, the 4:1 frame ratio gave poorest diversion with acute slat angles, but allowed use of oblique slats (30°) which resulted in high diversion success. For anaesthetized fish, the 4:1 frame ratio resulted in the best overall passive diversion. From the results of this study, it is clear that all test variables are to some degree correlated. This is especially true of the parameters frame ratio, slat spacing and slat angle, as all three parameters affect the actual separation of slats in a louvre array. Slat separation is the distance between

successive slats in the array (measured parallel to the flume walls, ie, in the direction of current flow)*. Regressions were fitted relating slat separation and percentage diversion to determine whether the combined effects of frame ratio, slat spacing and slat angle might be adequately described by this single variable. Measured separation values, percentage diversions, and regressions are listed in Appendices 3 and 4 for active and anesthetized trout, respectively. Results are summarized in Figure 5. In tests of active trout, regressions for the three test velocities are very similar (Figure 5A). There is a slight suggestion of reduced diversion at the highest velocity (40 cm/s) but this difference is rather small. In contrast to active diversion, passive diversion regressions (Figure 5B) clearly show the effects of current velocity. Higher current velocities resulted in a progressive downward displacement of regression lines (lower intercept values) and also increased the slope of the regression lines.

Regressions were also fitted combining the results for all velocities (Figure 5C). Regression slopes for active and passive diversion were almost identical, with diversion values for anaesthetized fish averaging approximately 10% below those of active fish.

While slat separation clearly affects the diversion success in a louvre array, considerable variability is present in the data. Correlation coefficients for the active diversion regressions (Figure 5A) ranged from -0.56 to -0.59. Combining velocities (Figure 5C) did not improve the regression fit ($r = 0.57$). Correlation coefficients for the passive regressions (Figure 5B) were somewhat lower, ranging from -0.44 to -0.54. Combining results for the three test velocities actually reduced the correlation coefficient ($r = -0.43$) due to the substantial effect of current velocity on passive diversion. Scatter plots were constructed to determine whether a consistent pattern of non-linearity was present in the data. Means plus standard deviations are shown for each slat separation (nine replicates) in Figure 6. There is no clear indication of non-linearity, but the results do suggest that variability in the data increased with increasing slat separation. Also, as might be expected due to a significant effect from current velocity, variability around the passive regression (Figure 6B) was somewhat larger

* Slat separation (as measured here) was equivalent to the actual clear opening (measured perpendicular to slat surfaces) when slat angle = 90°. As slat angle decreased, clear openings became smaller than slat separation (see Appendix 7).

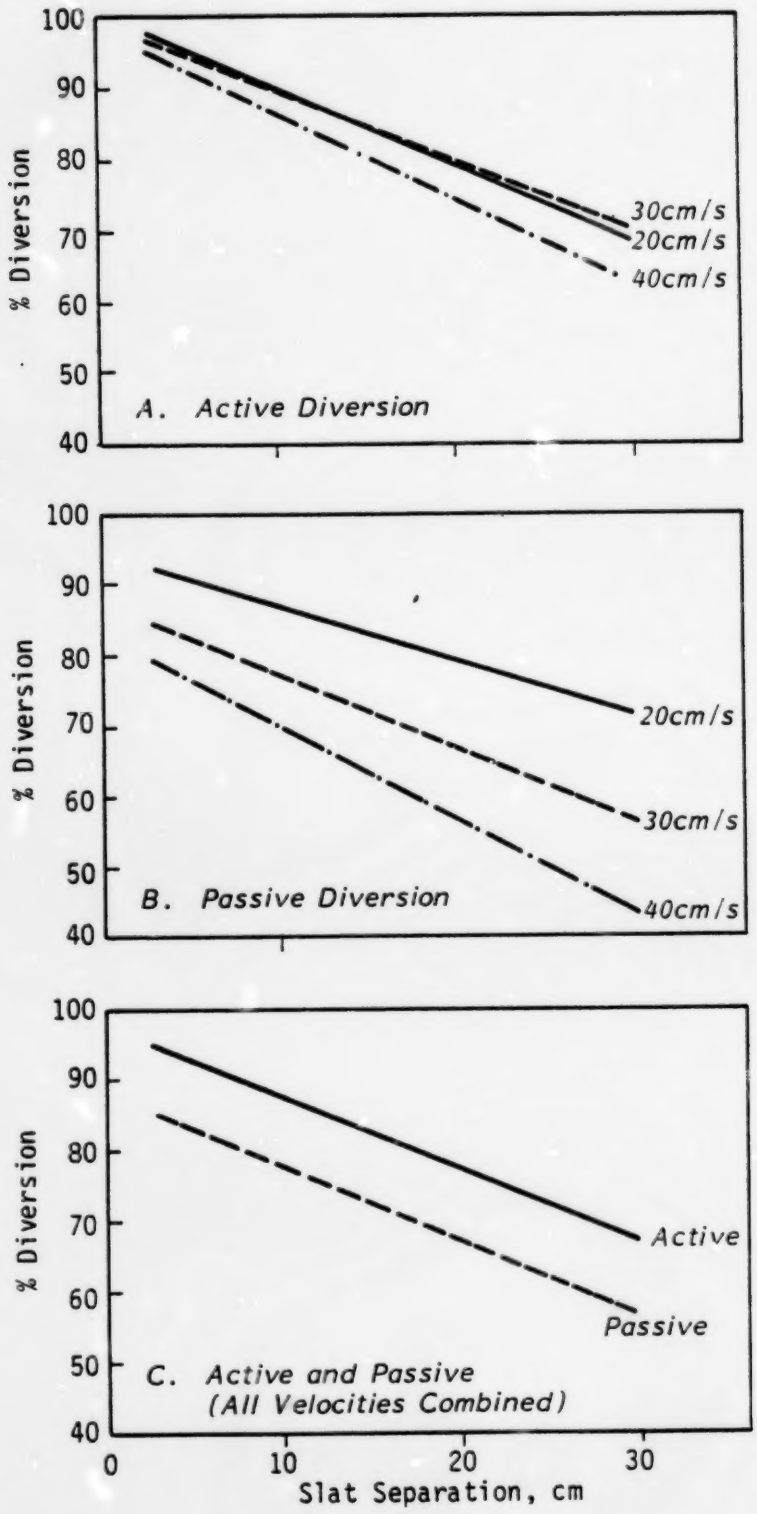
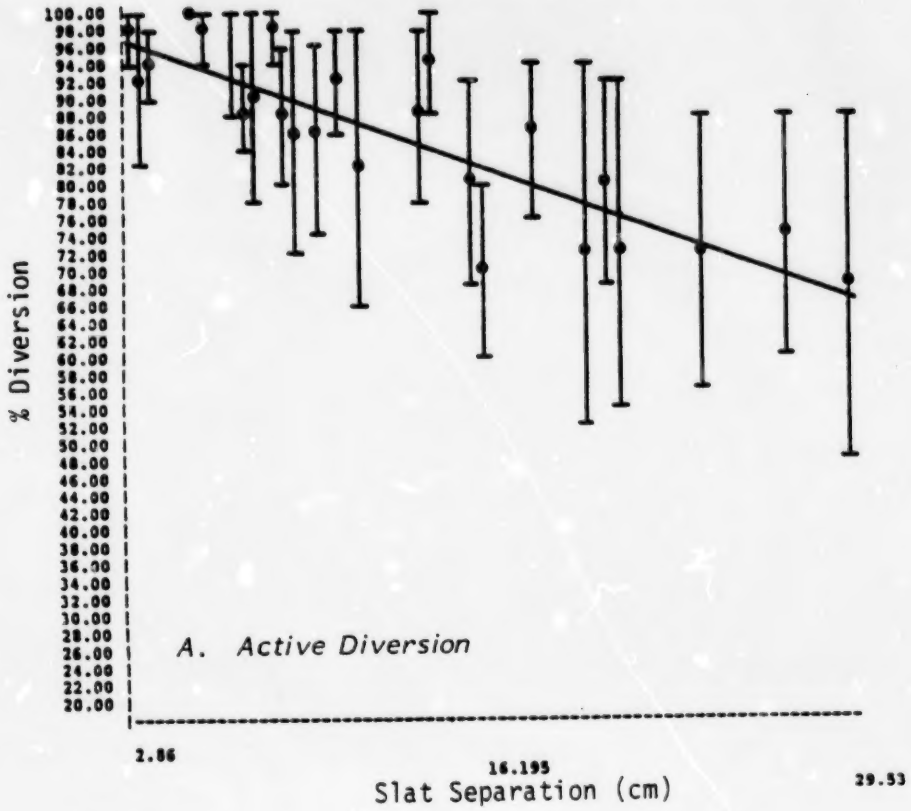


FIGURE 5

REGRESSIONS OF PERCENTAGE DIVERSION AGAINST LOUVRE SLAT SEPARATION



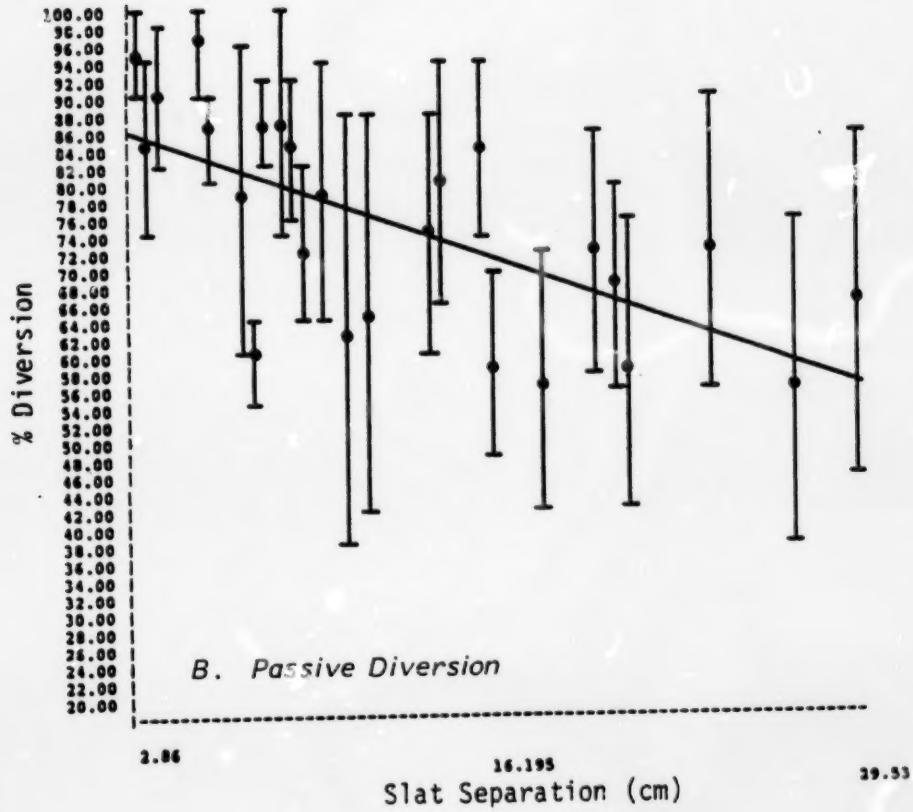


FIGURE 6

REGRESSIONS AND SCATTER PLOTS -
ALL VELOCITIES COMBINED

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than that around the active regression (Figure 6A). The regressions shown in Figures 5 and 6 indicate the importance of minimal louvre slat separation to obtain high diversion success. Through reference to the data plots in Figures 2 and 3 and the listing of measured separation values (Appendix 7) it is possible to determine those combinations of frame ratio, slat spacing and slat angle which will yield high diversion success.

3.4 Ancilliary Tests

A small number of ancilliary tests was conducted with rainbow trout in darkness and with gizzard shad and rainbow smelt (both in daylight). The first series of rainbow trout dark tests (three replicates) was run using a 2:1 frame ratio, 20 cm slat spacing, 30 cm/s velocity and 90° slat angle. Diversion of active trout in darkness averaged 94.5% (range 88.9% to 100.0%) compared with an average daylight value (previously discussed tests) of 84.2% (range 70.0% to 95.7%). Passive diversion in darkness averaged 66.7% (60% to 72% range) compared with 50.7% (36% to 60% range) observed in the daylight tests. The second series of rainbow trout dark tests used similar louvre parameters, but the slat angle was reduced to 45°. Average active diversion in these dark tests was 98.0% (94.1% to 100% range), comared with a 90.8% average (82.6% to 95.7% range) obtained in the daylight tests. Passive diversion in these dark tests averaged 73.3% (64% to 92% range) compared with a daylight value of 84.0% (80% to 92% range). Thus, results suggest that the louvre arrays tested in this study will be equally effective in darkness and daylight.

Tests with gizzard shad (daylight, two replicates) used a 4:1 frame ratio, 30 cm slat spacing, 30 cm/s velocity and 67.5° slat angle. Mean active diversion was 80.9%, compared with a mean of 76.0% for rainbow trout tested in these conditions. Mean passive diversion of shad was 92.0%, compared with 80.0% obtained from anaesthetized rainbow trout. The shad used in these experiments were small to medium sized adults (approximately 30 cm in length). Thus, it is apparent that the louvre systems tested in the present study with juvenile rainbow trout will be at least as effective (and possibly better) at diverting larger fish.

Only one test was conducted with rainbow smelt (adults approximately 15 cm long). The 2:1 frame ratio, 30 cm slat spacing, 67.5° slat angle, and 40 cm/s velocity were tested in daylight. Active diversion was 88% compared with 78.3% (57.9% to 89.5% range) obtained from rainbow trout under these conditions. Passive diversion of both smelt and rainbow trout was 56.0%. While limited, the comparison suggests that present trout data should be representative of small pelagic Great Lakes species.

4.0 DISCUSSION

The concept of using louvre vanes to guide fish to specific areas of a forebay (bypass) appears to have been developed by Kerr (1953) in studies at the PG&E Contra Costa Steam Plant. Kerr noted that when obstructions were introduced into a test flume, they created vertical stream lines of differing velocities which fish were reluctant to cross. Kerr conducted a number of diversion experiments in a flume of similar depth and width to that used in the present study, using wedge-shaped louvre slats. He reported a 92% diversion for several species (of varying sizes) with a deflection angle (frame angle) of 30° and a vane (slat) angle of 10° to the frame. Relative to the present study, this is equivalent to a 1.5:1 frame ratio and a 40° slat angle. Present results also suggest that a high diversion efficiency (85 to 95%) might be expected from this arrangement.

Later studies, primarily directed at developing a louvre diversion system for the Delta-Mendota Canal in California, stressed the principle that fish will avoid areas of high turbulence and will not cross through a vertical line of high differential velocity (Hallock et al, 1968). Effects of fish swimming speed, louvre angle and approach velocity were discussed in detail by Bates and Vinsonhaler (1956) and Bates et al (1960). However, it is noteworthy that these studies, and later investigations of louvre systems for power plant application (Stone and Webster 1975, 1977; reviews by MacLaren, 1975; Ray et al, 1976) appear to have concentrated on louvre systems in which the slats were attached perpendicular to the louvre frame. This arrangement would divert flow through the louvre slats rather than towards the fish bypass and virtually eliminates any possibility of passive diversion of test fish. MacLaren (1975) pointed out that Stone and Webster's (1975) results were not entirely applicable to the Great Lakes situation as the alewife used in those studies were obtained from small lakes (presumably robust specimens) and were not tested at low temperatures (below 11°C). Given that the louvre arrays tested by Stone and Webster required strong, active swimming by the fish to avoid entrainment through the louvre slats, this criticism would appear valid. However, if louvre systems which promote diversion of both active and moribund fish are considered, the concerns raised by MacLaren (1975) are of less importance.

The present study appears to be the only case where passive diversion of unhealthy, moribund, or in this case, anaesthetized fish has been considered in detail. Given the previous emphasis on the behavioral response of fish to louvre turbulence, and the use of louvre slats perpendicular to support frames, it is not particularly surprising. Only the louvre slat arrangements of

the present study and those used by Kerr (1953) would be expected to produce significant passive diversion. In the present study, passive diversion averaged 10% lower than active diversion. Limited tests with smelt and gizzard shad sugest that present trout results are probably applicable to these Great Lakes species (and presumably, alewife as well). The high passive diversion success obtained in shad tests suggests that even better results may be obtained with larger fish, despite factors such as low temperatures and poor fish condition (possibly from cold-shock).

Active and passive diversion of rainbow trout was not affected to the same degree by the louvre parameters tested (frame ratio, slat spacing, slat angle, velocity). Thus it is possible to select combinations of parameters which will yield very high rates of diversion for both active and passive fish. A frame ratio of 4:1 with 10 cm slat spacing and 45° slat angles is one example. Active diversion was 100% for this combination and passive diversion averaged 96% (100%, 100% and 89%, respectively for 20, 30 and 40 cm/s velocities). A somewhat more economical (to build) combination (with slightly less effectiveness) is a 2:1 frame ratio with 20 cm slat spacing and 45° slat angle. Active diversion averaged 94% and passive diversion averaged 84% for this combination. If the objective is to remove all fish (or as many as possible) from the intake flow, regardless of their condition, present results suggest the louvre design parameters to attain this objective. A further objective might be the separation of healthy and moribund fish prior to returning the healthy fish to the lake. In this case, if the downstream section of the louvre array were modified to reduce passive diversion, yet maintain a high level of active diversion, separation of healthy and moribund fish might be achieved. A possible combination which might achieve this effect is a frame ratio of 2:1, slat spacing of 10 cm, slat angle of 67.5° and a relatively high velocity (40 cm/s). In the present study, an active diversion of 96% and a passive diversion of 53% were obtained under these conditions (in a 1.2 m wide flume). A few metres of louvre set at these angles might be sufficient to obtain a high percentage separation of active and moribund fish.

Many questions regarding the cost, feasibility of construction and potential for debris or ice fouling must be resolved before louvres can be recommended for use at Ontario Hydro CCW intake systems. However, the present study has demonstrated that louvre systems are capable of a high degree of diversion for both active and moribund fish ranging in size from 15 cm (adult smelt, alewife, juvenile trout used in this study) to 30 cm (adult shad). Also, results indicate that through manipulation of louvre design parameters, it may be possible to separate healthy and moribund fish at the downstream end of a louvre array, returning only the healthy specimens to the lake.

5.0 SUMMARY

1. Experiments were conducted in a laboratory flume (15 m x 1.2 m x 1.2 m) to determine the effects of various louvre parameters (support frame ratio, slat spacing, slat angle, water velocity) on fish diversion success. The large number of experimental trials (81 treatment combinations x 3 replicates) required the use of a test species which was readily available and would remain healthy for an extended period. Juvenile rainbow trout (15 cm in length) were used for these studies. After each test, trout were anaesthetized and re-tested to determine the ability of each louvre array to passively divert fish (simulation of moribund condition). In addition to the above experiments (run under low level daylight), trout were tested (with a restricted set of louvre parameters) in complete darkness. A few tests (in daylight) were also run using adult gizzard shad and adult rainbow smelt.

2. Louvre slat angle and slat spacing were the factors most strongly affecting diversion of active rainbow trout. Averaged over all other parameters, diversion increased linearly from 81% with a 90° slat angle (relative to current flow) to 95% with a 30° slat angle. Diversion success also increased linearly with decreased slat spacing (from 78% with 30 cm slat spacing to 93% with 10 cm slat spacing). Averaged over all treatments, the louvre frame ratio did not substantially affect active diversion. When used with acute slat angles (90°, 67.5°) the low frame ratios (1:1, 2:1) yielded better diversion than the 4:1 frame ratio. However, the 4:1 frame ratio allowed use of the most effective (30°, 45°) slat angles, and hence the best overall diversion success. Current velocity had a minor effect on diversion of active trout over the range of velocities tested (20 to 40 cm/s). Average diversion success at 40 cm/s current velocity (83.5%) was only slightly lower than the value (87%) observed for 20 cm/s and 30 cm/s velocities.

3. In general, passive diversion (of anaesthetized trout) averaged about 10% lower than active diversion. Slat angle and slat spacing both significantly affected passive diversion. Changes in diversion success relative to these parameters paralleled results for active trout. Best passive diversion was obtained with the oblique (4:1) frame ratio (79% average compared with 72% to 73% for 2:1 and 1:1 ratios). Unlike active diversion, passive diversion was significantly affected by approach velocity, declining from an average 84% diversion at 20 cm/s to 66% at 40 cm/s.

4. The louvre frame ratio, slat spacing and slat angles all affected the slat separation, that is, the actual clear spacing between successive slats in the louvre array. Regression of slat separation against percentage diversion resulted in a significant, basically linear relationship. For active fish(all velocities), diversion increased from 67.5% at a slat separation of 29.5 cm to 95% at 2.9 cm separation. The regression for passive diversion had a nearly identical slope, with diversion percentages approximately 10% lower. Regressions for active fish were little affected by current velocity. Passive diversion regressions had progressively steeper slopes and lower intercept values with increased approach velocity.

5. In darkness, both active and passive diversion of rainbow trout were comparable to results obtained (for the particular louvre arrays tested) in daylight. Hence, a louvre array would not need illumination in order to be effective. This would be especially true for those louvre arrays which produced high diversion percentages for both active and passive fish. Gizzard shad tests indicated that these larger fish (approximately 30 cm long) would be diverted with somewhat greater success than trout used in this study. Smelt results (15 cm adults) were almost identical to those obtained from trout (comparable size) under the particular louvre conditions tested.

6. This study appears to be the first to consider the passive diversion of moribund or unhealthy fish (here simulated by anaesthetized trout). The high passive diversion obtained appears to be the result of louvre slat angles (90° to 30°, relative to flow) which promote passive diversion. In contrast, previous studies of louvre systems for cooling water intakes have largely utilized slats attached perpendicular to the support frames, a condition which would divert flow through the louvre slats and yield very low passive diversion.

7. Certain combinations of louvre parameters (oblique frame ratios, close slat spacing, oblique slat angles) yielded very high active and passive diversion percentages. For example, a 4:1 frame ratio, 10 cm slat spacing and 45° slat angle resulted in 100% active diversion and 96% passive diversion for the nine tests conducted under these conditions (all velocities). A louvre system constructed to these parameters should be very effective at removing fish (adult smelt/alewife size or larger) from a cooling water flow, regardless of fish condition, water temperature, turbidity or illumination. Present results also suggest other parameter combinations which might be almost as

effective, but less expensive to construct. As active and passive diversion were not affected to the same degree by variation in louvre parameters, it may be possible to separate active and moribund fish once they have been removed from the general intake flow. In the present study, a 2:1 frame ratio, 10 cm slat spacing, 67.5° slat angle and 40 cm/s velocity resulted in a 96% active diversion, while passive diversion declined to 53%. If the last few metres of a louvre array was constructed to these parameters, reasonable separation of healthy and moribund fish could be achieved, and only the healthy fish returned to the lake.

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APPENDIX 1
PER CENT DIVERSION
FOR ACTIVE RAINBOW TROUT

SPACING	30	30	30	30	30	30	30	30	30
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	20	20	20	20	20	20	20	20	20
	68	92	72	84	76	68	68	88	100
	88	88	48	88	84	92	84	100	88
	64	92	88	68	96	84	88	96	92

SPACING	30	30	30	30	30	30	30	30	30
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	30	30	30	30	30	30	30	30	30
	60	68	60	68	56	60	88	76	84
	72	36	52	72	80	60	92	92	80
	40	76	64	64	72	88	60	84	84

SPACING	30	30	30	30	30	30	30	30	30
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	40	40	40	40	40	40	40	40	40
	52	36	24	60	52	64	44	76	72
	52	40	36	52	48	32	56	72	80
	32	56	64	56	60	44	76	76	80

SPACING	20	20	20	20	20	20	20	20	20
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	20	20	20	20	20	20	20	20	20
	88	84	68	92	96	76	60	80	84
	96	80	36	88	92	80	60	100	88
	88	96	72	88	92	80	72	88	92

SPACING	20	20	20	20	20	20	20	20	20
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	30	30	30	30	30	30	30	30	30
	80	92	36	76	92	64	76	80	88
	92	84	60	56	80	80	56	52	84
	56	84	56	72	80	36	48	48	76

APPENDIX 1 cont'd
PER CENT DIVERSION
FOR ACTIVE RAINBOW TROUT

SPACING	20	20	20	20	20	20	20	20	20
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	40	40	40	40	40	40	40	40	40
	68	92	80	56	60	76	52	32	84
	64	88	44	76	80	84	60	36	84
	84	80	60	64	84	72	40	48	92
SPACING	10	10	10	10	10	10	10	10	10
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	20	20	20	20	20	20	20	20	20
	64	92	80	92	84	88	88	100	100
	64	96	88	64	92	100	100	100	100
	60	96	80	92	100	92	96	100	88
SPACING	10	10	10	10	10	10	10	10	10
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	30	30	30	30	30	30	30	30	30
	60	92	72	96	92	88	96	100	88
	56	96	72	56	92	88	80	100	100
	52	80	56	96	72	84	100	100	100
SPACING	10	10	10	10	10	10	10	10	10
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	40	40	40	40	40	40	40	40	40
	56	76	68	52	72	92	68	84	92
	52	100	64	40	84	76	84	92	96
	68	84	76	68	76	88	68	92	88

APPENDIX 2
PER CENT DIVERSION
FOR PASSIVE RAINBOW TROUT

SPACING	30	30	30	30	30	30	30	30	30
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	20	20	20	20	20	20	20	20	20
	91.3	84	85	70.6	84	27.8	76.2	96	100
	52	100	52	77.3	88	66.7	90.9	72	72.2
	88	96	68.2	76.5	70.6	100	78.3	92	92
SPACING	30	30	30	30	30	30	30	30	30
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	30	30	30	30	30	30	30	30	30
	88.9	75	81.8	83.3	95	63.6	82.6	72	77.8
	72.2	89.5	82.4	85	85	55	90.9	56.5	95.5
	86.4	85.7	92	100	76.5	71.4	54.5	80	87.5
SPACING	30	30	30	30	30	30	30	30	30
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	40	40	40	40	40	40	40	40	40
	56.3	95	87.5	57.9	75	73.3	47.6	90.9	87.5
	78.6	52.4	56.3	87.5	82.4	80	77.8	85.7	91.3
	40	58.8	62.5	89.5	93.8	73.9	53.3	80	88.2
SPACING	20	20	20	20	20	20	20	20	20
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	20	20	20	20	20	20	20	20	20
	95.7	100	78.9	86.4	95	95.5	90.5	81.3	100
	95	95	90.9	94.7	100	87.5	55.6	95.7	100
	87.5	94.4	73.3	100	95.2	76	76.5	90	100
SPACING	20	20	20	20	20	20	20	20	20
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	30	30	30	30	30	30	30	30	30
	100	93.8	95.7	70.6	95.7	55.6	73.3	100	100
	95.7	89.5	87	86.7	82.6	91.3	61.1	93.8	100
	90.9	100	70	95.2	94.1	65	66.7	85	100

APPENDIX 2 cont'd
PER CENT DIVERSION
FOR PASSIVE RAINBOW TROUT

SPACING	20	20	20	20	20	20	20	20	20
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	40	40	40	40	40	40	40	40	40
	81.8	95	90.5	75	86.4	30.4	68.8	86.7	94.1
	92	63.2	94.1	90.9	94.1	75	68.2	94.1	87.5
	100	82.4	85.7	90	100	80	73.7	100	95.5
SPACING	10	10	10	10	10	10	10	10	10
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	20	20	20	20	20	20	20	20	20
	90.5	94.1	93.8	100	92	100	100	100	100
	90.5	95	62.5	88.9	100	89.5	94.4	100	100
	94.7	90	80	85.7	88.9	68.8	100	100	100
SPACING	10	10	10	10	10	10	10	10	10
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	30	30	30	30	30	30	30	30	30
	90	86.7	96	100	100	88.9	100	100	100
	80.9	96	100	87.5	100	95	100	100	90
	95.2	94.1	87	100	84.2	94.4	100	100	100
SPACING	10	10	10	10	10	10	10	10	10
ANGLE	90	67.5	90	67.5	45	90	67.5	45	30
RATIO	1:1	1:1	2:1	2:1	2:1	4:1	4:1	4:1	4:1
CURRENT	40	40	40	40	40	40	40	40	40
	89.5	100	95.2	95.7	73.7	60	88.9	100	95.5
	83.3	100	77.8	95.8	86.7	100	100	100	100
	85	94.7	75	95.7	94.1	93.3	100	100	100

APPENDIX 3
ACTIVE RAINBOW TROUT REGRESSION
PER CENT DIVERSION VS SLAT SEPARATION (cm)

SEPARATION	2.86	2.86	2.86	3.34	3.34	3.34	3.81	3.81	3.81
VELOCITY	20	30	40	20	30	40	20	30	40
	100	100	95.5	92	100	73.7	94.1	86.7	100
	100	90	100	100	100	86.7	95	96	100
	100	100	100	88.9	84.2	94.1	90	94.1	94.7
SEPARATION	5.24	5.24	5.24	5.72	5.72	5.72	6.67	6.67	6.67
VELOCITY	20	30	40	20	30	40	20	30	40
	100	100	100	100	100	94.1	95	95.7	86.4
	100	100	100	100	100	87.5	100	82.6	94
	100	100	100	100	100	95.5	95.2	94.1	100
SEPARATION	6.83	6.83	6.83	6.99	6.99	6.99	7.62	7.62	7.62
VELOCITY	20	30	40	20	30	40	20	30	40
	100	100	95.7	90.5	90	89.5	100	93.8	95
	88.9	87.5	95.8	90.5	80.9	83.3	95	89.5	63.2
	85.7	100	95.7	94.7	95.2	85	94.4	100	82.4
SEPARATION	8.09	8.09	8.09	8.57	8.57	8.57	9.05	9.05	9.05
VELOCITY	20	30	40	20	30	40	20	30	40
	100	100	88.9	100	77.8	87.5	93.8	96	95.2
	94.4	100	100	72.2	95.5	91.3	62.5	100	77.8
	100	100	100	92	87.5	88.2	80	87	75
SEPARATION	9.84	9.84	9.84	10	10	10	10.48	10.48	10.48
VELOCITY	20	30	40	20	30	40	20	30	40
	100	88.9	60	84	95	75	81.3	100	86.7
	89.5	95	100	88	85	82.4	95.7	93.8	94.1
	68.8	94.4	93.3	70.6	76.5	93.8	90	85	100
SEPARATION	11.43	11.43	11.43	13.65	13.65	13.65	13.97	13.97	13.97
VELOCITY	20	30	40	20	30	40	20	30	40
	84	75	95	86.4	70.6	75	95.7	100	81.8
	100	89.5	52.4	94.7	86.7	90.9	95	95.7	92
	96	85.7	58.8	100	95.2	90	87.5	90.9	100

APPENDIX 3 cont'd
ACTIVE RAINBOW TROUT REGRESSION
PER CENT DIVERSION VS SLAT SEPARATION

SEPARATION	15.71	15.71	15.71	16.19	16.19	16.19	18.10	18.10	18.10
VELOCITY	20	30	40	20	30	40	20	30	40
	96	72	90.9	90.5	73.3	68.8	78.9	95.7	90.5
	72	56.5	85.7	55.6	61.1	68.2	90.9	87	94.1
	92	80	80	76.5	66.7	73.7	73.3	70	85.7

SEPARATION	19.69	19.69	19.69	20.48	20.48	20.48	20.96	20.96	20.96
VELOCITY	20	30	40	20	30	40	20	30	40
	95.5	55.6	30.4	70.6	83.3	57.9	91.3	88.9	56.3
	87.5	91.3	75	77.3	85	87.5	52	72.2	78.6
	76	65	80	76.5	100	89.5	88	86.4	40

SEPARATION	24.29	24.29	24.29	27.15	27.15	27.15	29.53	29.53	29.53
VELOCITY	20	30	40	20	30	40	20	30	40
	76.2	82.6	47.6	85	81.8	87.5	27.8	63.6	73.3
	90.9	90.9	77.8	52	82.4	56.3	66.7	55	80
	78.3	54.5	53.3	68.2	92	62.5	100	71.4	73.9

REGRESSIONS:

20 cm/s velocity:	Y = 100.98 - 1.09185X	r = -0.5792
30 cm/s velocity:	Y = 99.88 - 1.01016X	r = -0.5898
40 cm/s velocity:	Y = 98.33 - 1.19597X	r = -0.5614
All Velocities:	Y = 99.73 - 1.09931X	r - -0.5685

Y = % Diversion
X = Slat Separation (cm)

APPENDIX 4
PASSIVE RAINBOW TROUT REGRESSION
PER CENT DIVERSION VS SLAT SEPARATION (cm)

SEPARATION	2.86	2.86	2.86	3.34	3.34	3.34	3.81	3.81	3.81
VELOCITY	20	30	40	20	30	40	20	30	40
	100	88	92	84	92	72	92	92	76
	100	100	96	92	92	84	96	96	100
	88	100	88	100	72	76	96	80	84
SEPARATION	5.24	5.24	5.24	5.72	5.72	5.72	6.67	6.67	6.67
VELOCITY	20	30	40	20	30	40	20	30	40
	100	100	84	84	88	84	96	92	60
	100	100	92	88	84	84	92	80	80
	100	100	92	92	76	92	92	80	84
SEPARATION	6.83	6.83	6.83	6.99	6.99	6.99	7.62	7.62	7.62
VELOCITY	20	30	40	20	30	40	20	30	40
	92	96	52	64	60	56	84	92	92
	64	56	40	64	56	52	80	84	88
	92	96	68	60	52	68	96	84	80
SEPARATION	8.09	8.09	8.09	8.57	8.57	8.57	9.05	9.05	9.05
VELOCITY	20	30	40	20	30	40	20	30	40
	88	96	68	100	84	72	80	72	68
	100	80	84	88	80	80	88	72	64
	96	100	68	92	84	80	80	56	76
SEPARATION	9.84	9.84	9.84	10	10	10	10.48	10.48	10.48
VELOCITY	20	30	40	20	30	40	20	30	40
	88	88	92	76	56	52	80	80	32
	100	88	76	84	80	48	100	52	36
	92	84	88	96	72	60	88	48	48
SEPARATION	11.43	11.43	11.43	13.65	13.65	13.65	13.97	13.97	13.97
VELOCITY	20	30	40	20	30	40	20	30	40
	92	68	36	92	76	56	88	80	68
	88	36	40	88	56	76	96	92	64
	92	76	56	88	72	64	88	56	84

APPENDIX 4 cont'd
PASSIVE RAINBOW TROUT REGRESSION
PER CENT DIVERSION VS SLAT SEPARATION (cm)

SEPARATION	15.71	15.71	15.71	16.19	16.19	16.19	18.10	18.10	18.10
VELOCITY	20	30	40	20	30	40	20	30	40
	88	76	76	60	76	52	68	36	80
	100	92	72	60	56	60	36	60	44
	96	84	76	72	48	40	72	56	60

SEPARATION	19.69	19.69	19.69	20.48	20.48	20.48	20.96	20.96	20.96
VELOCITY	20	30	40	20	30	40	20	30	40
	76	64	76	84	68	60	68	60	52
	80	80	84	88	72	52	88	72	52
	80	36	72	68	64	56	64	40	32

SEPARATION	24.29	24.29	24.29	27.15	27.15	27.15	29.53	29.53	29.53
VELOCITY	20	30	40	20	30	40	20	30	40
	68	88	44	72	60	24	68	60	64
	84	92	56	48	52	36	92	60	32
	88	60	76	88	64	64	84	88	44

REGRESSIONS:

20 cm/s velocity: $Y = 94.47 - 0.788986X$ $r = -0.4377$
Confidence limits of slope = ± 0.2802

30 cm/s velocity: $Y = 87.71 - 1.05898X$ $r = -0.4524$
Confidence limits of slope = ± 0.3437

40 cm/s velocity: $Y = 83.19 - 1.33839X$ $r = -0.5364$
Confidence limits of slope = ± 0.3922

All velocities: $Y = 88.45 - 1.0261X$ $r = -0.4327$

Y = % Diversion
X = Slat Separation (cm)

APPENDIX 5

STATISTICAL ANALYSES FOR LOUVRE PARAMETERS - ACTIVE TROUT

1:1 FRAME RATIO:

THREE WAY ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SS	MS	F-RATIO
Spacing	2	2522.11	1261.06	10.74*
Current	2	1137.57	568.79	4.85*
Angle	1	217.60	217.60	1.85
A*B	4	911.73	227.93	1.94
A*C	2	342.42	171.21	1.46
B*C	2	78.72	39.36	0.34
A*B*C	4	375.40	93.85	0.80
Within	36	4225.81	117.38	
Total	53	9811.38		

2:1 FRAME RATIO:

THREE WAY ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SS	MS	F-RATIO
Spacing	2	1850.79	925.40	9.44*
Current	2	417.36	208.68	2.13
Angle	2	918.48	459.24	4.69*
A*B	4	713.81	178.45	1.82
A*C	4	215.48	53.87	0.55
B*C	4	354.51	88.63	0.90
A*B*C	8	412.25	51.53	0.53
Within	54	5293.01	98.02	
Total	80	10175.69		

APPENDIX 5 (cont'd)

STATISTICAL ANALYSES FOR LOUVRE PARAMETERS - ACTIVE TROUT

4:1 FRAME RATIO:

THREE WAY ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SS	MS	F-RATIO
Spacing	2	6671.94	3335.97	23.00*
Current	2	327.82	163.91	1.13
Angle	3	6041.09	2013.70	13.88*
A*B	4	335.66	83.92	0.58
A*C	6	1833.46	305.58	2.11
B*C	6	382.43	63.74	0.44
A*B*C	12	1897.67	158.14	1.09
Within	72	10443.56	145.05	
Total	107	27933.64		

APPENDIX 6

STATISTICAL ANALYSES FOR LOUVRE PARAMETERS - PASSIVE TROUT

1:1 FRAME RATIO

THREE WAY ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SS	MS	F-RATIO
Spacing	2	4155.26	2077.63	18.36*
Current	2	2916.15	1458.07	12.88*
Angle	1	2962.96	2962.96	26.18*
A*B	4	1786.07	446.52	3.95*
A*C	2	1794.37	897.19	7.93*
B*C	2	7.70	3.85	0.03
A*B*C	4	594.96	148.74	1.31
Within	36	4074.67	113.19	
Total	53	18292.15		

2:1 FRAME RATIO

THREE WAY ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SS	MS	F-RATIO
Spacing	2	2057.88	1028.94	6.97*
Current	2	5499.65	2749.83	18.64*
Angle	2	4072.69	2036.35	13.80*
A*B	4	735.60	183.90	1.25
A*C	4	1088.79	272.20	1.84
B*C	4	548.35	137.09	0.93
A*B*C	8	1045.73	130.72	0.89
Within	54	7968.00	147.56	
Total	80	23016.69		

APPENDIX 6 (cont'd)

STATISTICAL ANALYSES FOR LOUVRE PARAMETERS - PASSIVE TROUT

4:1 FRAME RATIO

THREE WAY ANALYSIS OF VARIANCE TABLE

SOURCE	DF	SS	MS	F-RATIO
Spacing	2	8956.74	4478.37	46.79*
Current	2	5134.52	2567.26	26.83*
Angle	3	3904.44	1301.48	13.60*
A*B	4	880.59	220.15	2.30
A*C	6	2987.56	497.93	5.20*
B*C	6	1416.00	236.00	2.47*
A*B*C	12	2378.67	198.22	2.07*
Within	72	6890.67	95.70	
Total	107	32549.19		

APPENDIX 7

LOUVRE SLAT SEPARATIONS FOR VARIOUS LOUVRE PARAMETER COMBINATIONS

	Slat Separation (Clear Opening)* (cm)		Frame Ratio	Slat Angle (° to Flow)	Slat Spacing (cm)
1	2.86	(1.43)	4:1	30	10
2	3.34	(2.36)	2:1	45	10
3	3.81	(3.52)	1:1	67.5	10
4	5.24	(3.71)	4:1	45	10
5	5.72	(2.86)	4:1	30	20
6	6.67	(4.72)	2:1	45	20
7	6.83	(6.31)	2:1	67.5	10
8	6.99	(6.99)	1:1	90	10
9	7.62	(7.04)	1:1	67.5	20
10	8.09	(7.47)	4:1	67.5	10
11	8.57	(4.29)	4:1	30	30
12	9.05	(9.05)	2:1	90	10
13	9.84	(9.84)	4:1	90	10
14	10.00	(7.07)	2:1	45	30
15	10.48	(7.49)	4:1	45	20
16	11.43	(10.56)	1:1	67.5	30
17	13.65	(12.61)	2:1	67.5	20
18	13.97	(13.97)	1:1	90	20
19	15.71	(11.11)	4:1	45	30
20	16.19	(14.96)	4:1	67.5	20
21	18.10	(18.10)	2:1	90	20
22	19.69	(19.69)	4:1	90	20
23	20.48	(18.92)	2:1	67.5	30
24	20.96	(20.96)	1:1	90	30
25	24.29	(22.44)	4:1	67.5	30
26	27.15	(27.15)	2:1	90	30
27	29.53	(29.53)	4:1	90	30

* Slat Separation = distance between slats measured parallel to flow

Clear Opening = distance between slats measured perpendicular to slat face

Note: when slat angle = 90°, Slat Separation equals Clear Opening